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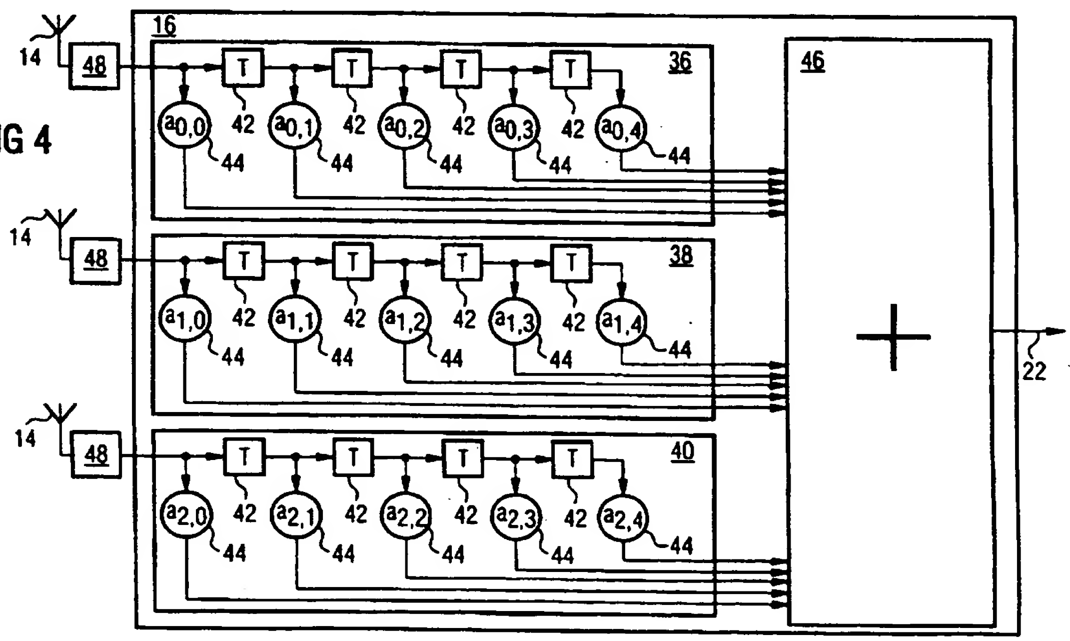
(54) Abstract Title
Radio communications receiver

(57) A radio communications receiver for use in recovering data from wide band radio signals which reach the receiver via a plurality of different paths, each path being associated with one of a plurality of different mean delays, the receiver comprising a plurality of antennas (14) arranged to detect the radio signals, each antenna (14) providing a data signal representative of a version of the detected radio signals, a plurality of scaling filters (36, 38, 40), each of which is coupled to a corresponding one of the plurality of antennas (14), each scaling filter (36, 38, 40) operating to scale the data signal with a plurality of scaling coefficients ($a_{n,m}$), a combiner means (46) coupled to the plurality of scaling filters (36, 38, 40), which operates to combine the scaled data signals into a composite signal, a data detector means (34) Fig.3, (not shown) which operates substantially to recover the data from the composite signal (z_i) and a detector controller (26) which operates to adapt the scaling coefficients consequent upon an error signal (e_i) derived from the composite signal.

FIG 4



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

FIG 1 PRIOR ART

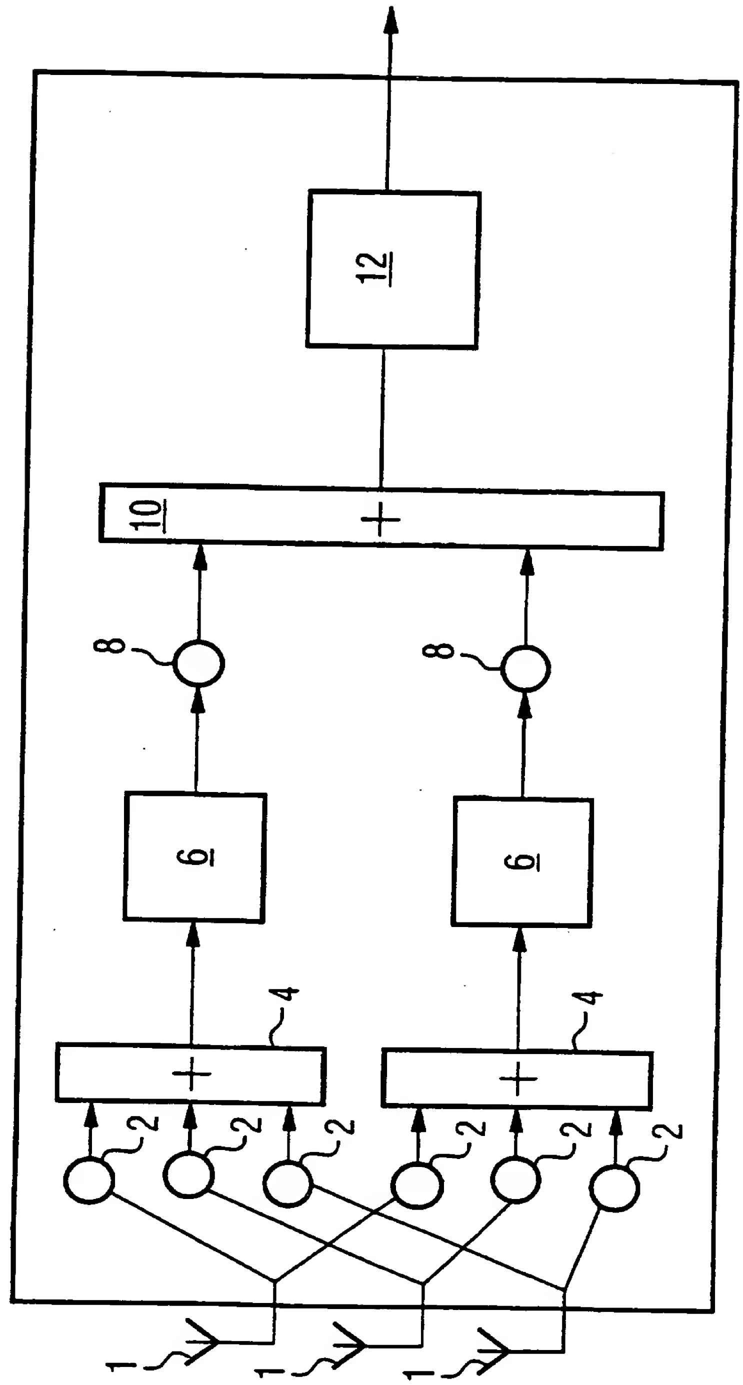


FIG 2

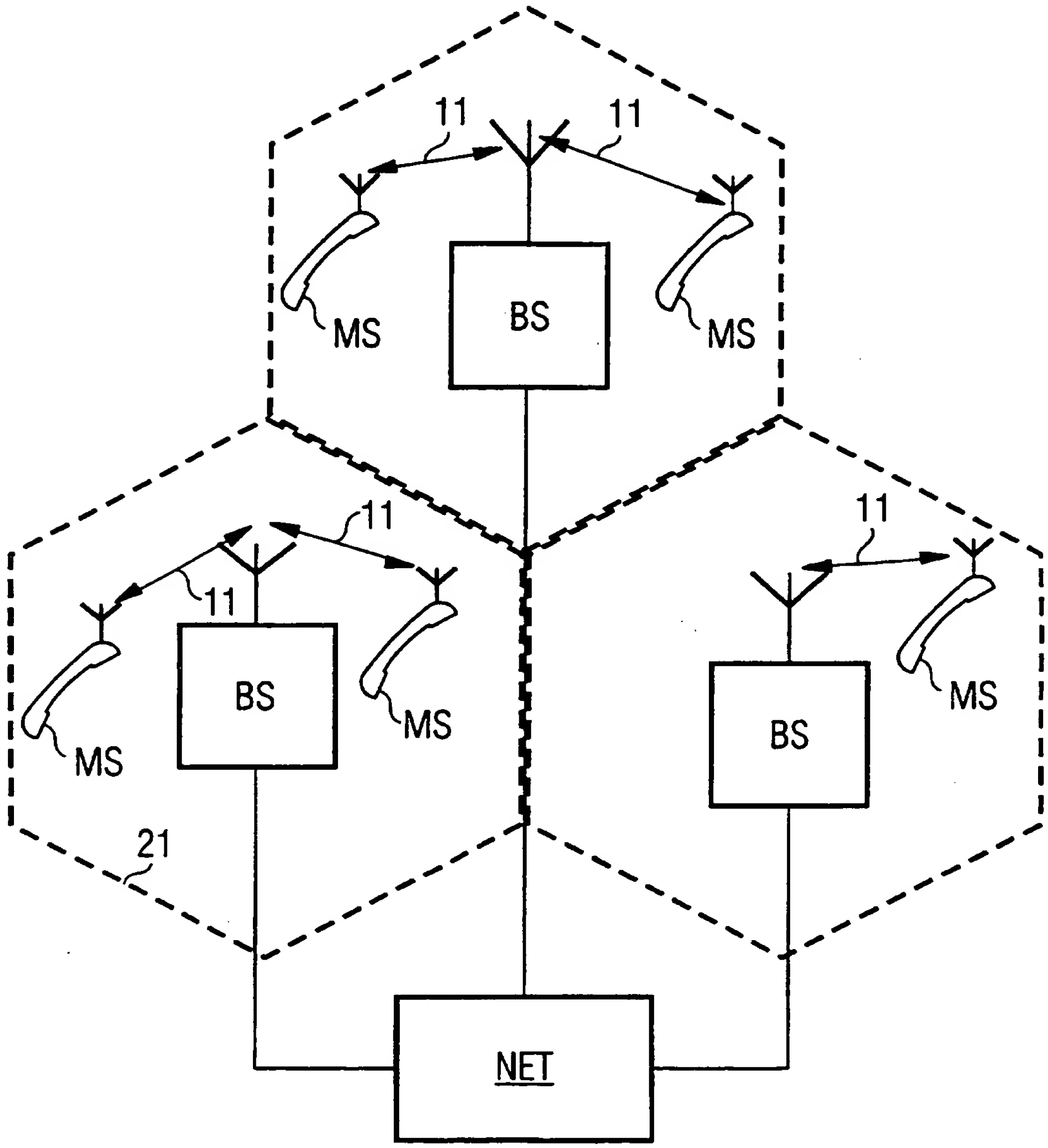
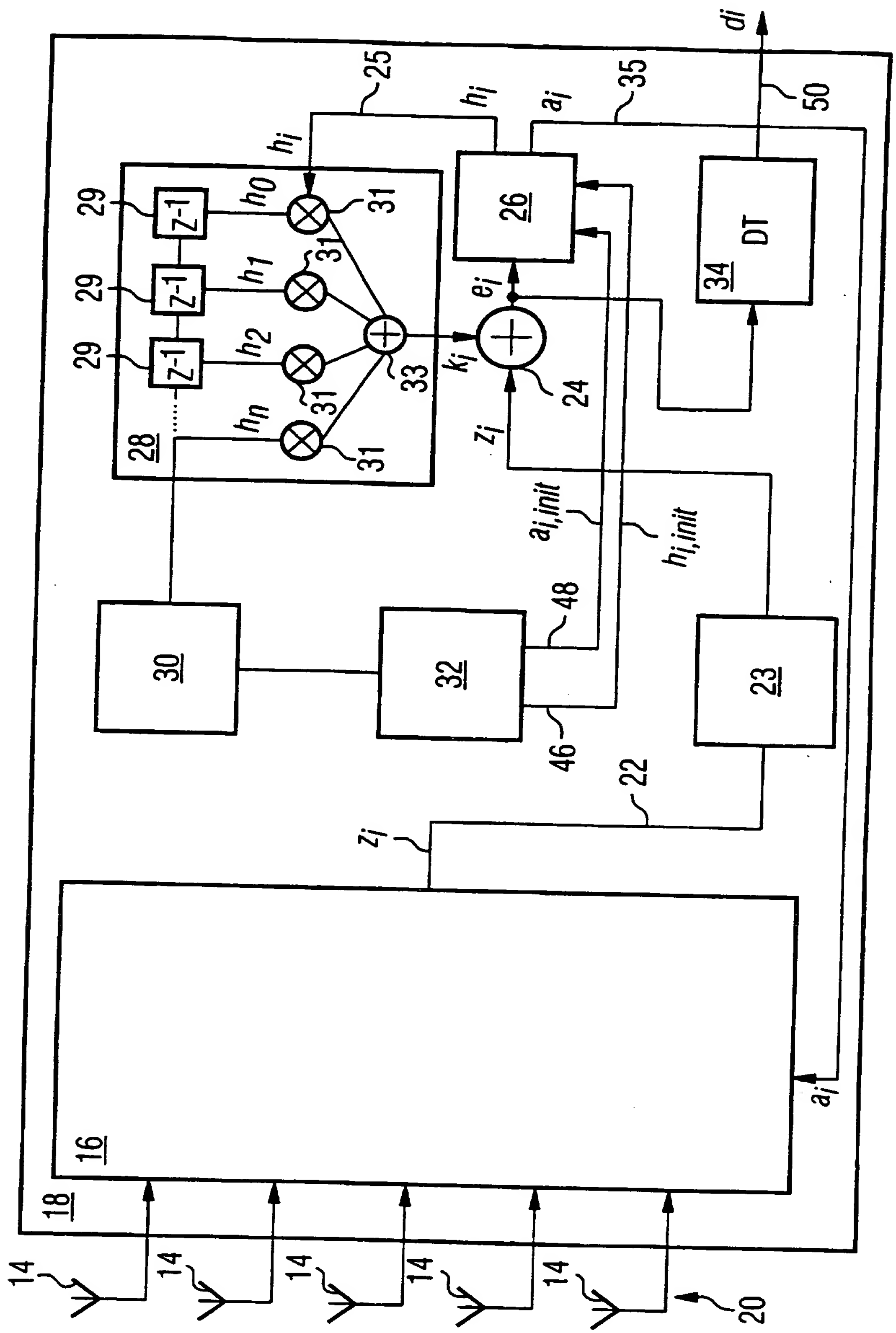


FIG 3



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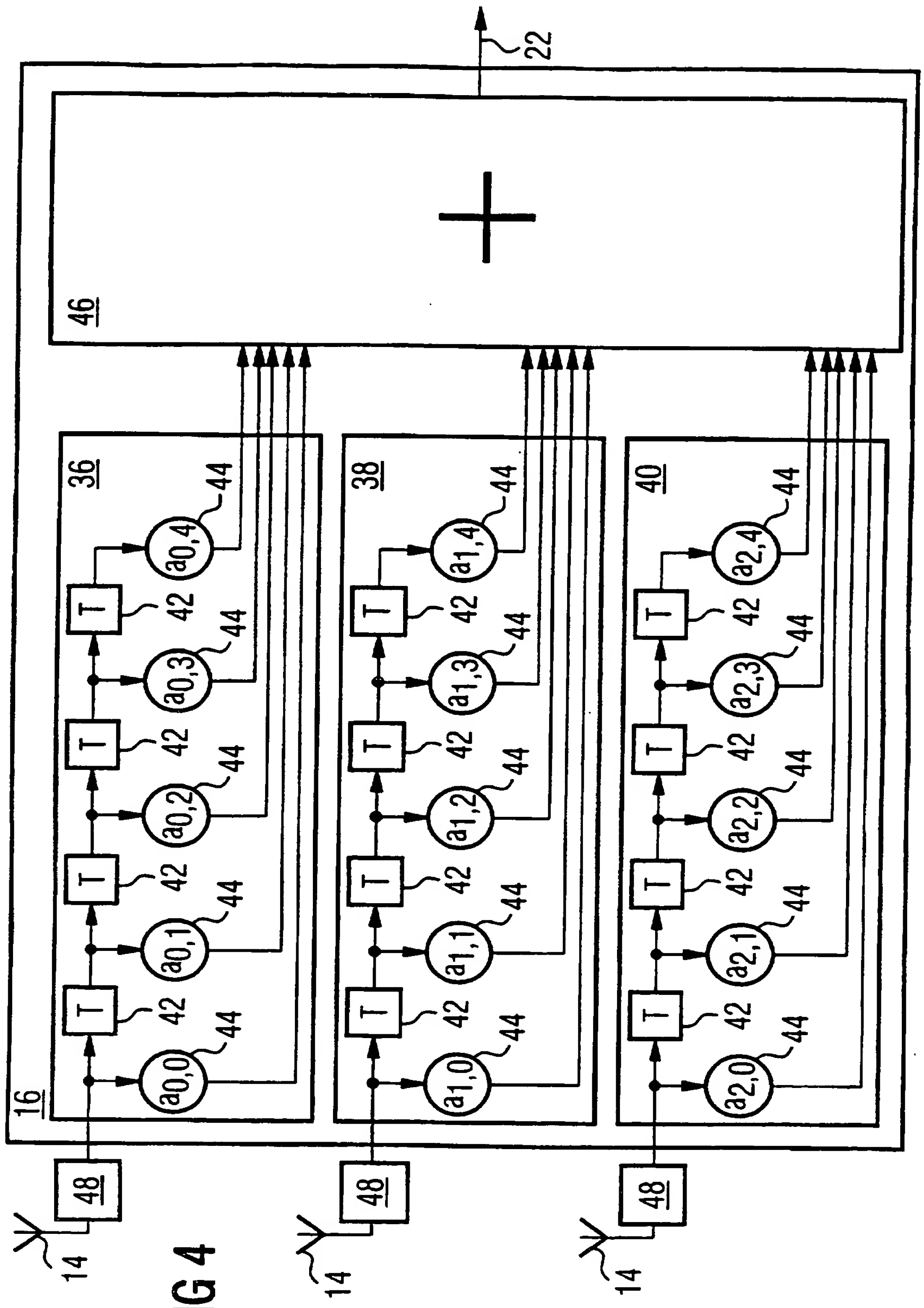
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FIG 4

Description

Communications receiver and method of detecting data from received signals

The present invention relates to radio communications receivers which operate to detect radio signals and recover data communicated by the radio signals. Furthermore the present invention relates to methods of recovering data from detected radio signals. More particularly, the present invention relates to radio communications receivers which employ adaptive antenna systems to facilitate the detection and recovery of data from radio signals.

Radio communications systems operate to communicate data by transmitting radio signals representative of the data between a transmitter and a receiver. Some radio communications systems include means for representing each datum to be communicated as plurality of symbols which are arranged to modulate a carrier signal. Receivers of the communications system operate to detect the radio signals and to process the detected signals in order to regenerate each datum which the modulating symbols represent.

An example of a radio communications system in which data is communicated as a plurality of modulating symbols is a mobile radio communications system which operates according to a code division multiple access radio communications technique. Code division multiple access (CDMA) is a radio access technique in which data to be communicated is combined with a spreading code or sequence in some way. The spreading code is then arranged to modulate a radio frequency carrier signal. In this way, each datum is represented as a plurality of modulating symbols corresponding to the symbols of at least part of the spreading code, which modulate the radio frequency carrier signal. The modulating symbols of the code are known as chips. At a receiver, the radio signal

is detected and compared with a local version of the spreading code, in order to recover the modulating data. The spreading code provides a gain in the power of the received signal with respect to noise for the code associated with a particular transmitter. This gain is known as a spreading gain. Other signals from other transmitters using different spreading codes appear as wide bandwidth noise to the receiver for this particular transmitter. Furthermore the spreading code has an effect of increasing the bandwidth of the transmitted radio signals thereby providing substantial resistance to the effects of time and frequency selective fading.

A characteristic of receivers for CDMA signals is that the data must be recovered in the presence of contemporaneously detected unwanted interfering signals. Receivers for detecting and recovering data from radio signals in the presence of interfering signals are known to include adaptive antenna arrays which operate to substantially reduce the effects of the interfering signals. An example of this can be found in our co-pending United Kingdom patent application serial number 9810ø987.9, in which a radio receiver having an adaptive antenna system is disclosed. The adaptive antenna system is comprised of a plurality of antennas, each of which is coupled to a means for scaling signals detected by the antenna by a scaling coefficient thereby weighting the version of the received signal in both amplitude and phase. The weighting provided by each coefficient has an effect that signals arriving at the antenna array from within a beam extending from the antenna array will add constructively. As a result, signals arriving at the antenna array from within this beam will experience a gain in terms of the signal to interference power ratio and therefore the data which these signals represent will be more likely to be correctly detected than other signals arriving from outside the beam.

A receiver which includes an adaptive antenna system and is arranged to detect data communicated by, for example, CDMA signals is shown in FIGURE 1. In Figure 1 three antennas 1, form an antenna array. Each of the antennas 1, is connected to a corresponding scaling means 2, which operates to scale a version of the received signal detected by the antenna 1, by a scaling coefficient, the result being fed to a combiner means 4. Each of the combiner means 4 operates to combine the scaled versions of the received signal, and feeds the combined signals to a delay means 6. Each of the delay means 6 operates to delay the combined signals fed from the combiner means 4 to the effect of compensating for the relative delays between the radio signals. The delayed signals are then further scaled by a further scaling means 8, and then combined by a further combiner 10, to form a composite signal fed to a data detector 12. The data detector 12, operates to recover the data from the composite signal.

In operation the receiver shown in Figure 1 is arranged to improve a probability of correctly recovering the data from the radio signals by steering a beam formed by the adaptive antenna system in a direction in which the wanted signals are incident, which has an effect of reducing a signal power of interfering signals incident at the adaptive antenna array from other directions falling outside the beam. The adaptive antenna system formed by the antennas 1, the coefficient scalers 2, and the combiner means 4, operate to form this coherent detection beam by calculating a direction of arrival of the wanted signal using for example a data processor operating to effect a direction of arrival process known as (ESPRIT) which is published in an article entitled 'ESPRIT - Estimation of Signal Parameters Via Rotational Invariance Techniques' by Richard Roy and Thomas Kailath published in the I.E.E.E Transactions on Acoustics, Speech and Signal Processing Volume 37, No. 7 July 1989. The ESPRIT direction of arrival process operates to determine a direction of incidence of the wanted radio signals and to effect

calculation of the antenna coefficients, which are applied by the scaling means 2, to scale the versions of the received signals. This has an effect of controlling the direction of the beam formed by the antenna so that it points in a direction of the wanted signal. After being scaled by the antenna coefficients each version of the received signal is combined by the combiner means 4, to which the scaler means 2 are connected. Each of the combiner means 4 is associated with one of two different mean delays.

Radio signals having a frequency within a radio frequency bandwidth which is typical of mobile radio systems such as the Global System for Mobiles (GSM), and that proposed for third generation systems known as the Universal Mobile Telecommunications System (UMTS), are known to travel between a transmitter and a receiver via a plurality of different paths. In a case where the signals themselves have a bandwidth which is substantially greater than a coherence bandwidth of a communications channel representative of the passage of signals through this radio frequency bandwidth, these paths may be resolved into one of a number of separate clusters. Such signals are known as wide band radio signals. Each of these clusters of paths has approximately the same mean delay associated with the passage of signals via those paths. Each of the combiner means 4, is therefore associated with a different one of these clusters of paths. After scaling by the antenna coefficients, the versions of the radio signals which reach the antenna array via each path within a cluster of paths are combined coherently by the combiner means 4. There therefore remains a task of time aligning the mean delay of the coherently combined signals and combing these to form a final composite signal. This task is performed by the delay means 6, in combination with the further scalers 8, which in combination with the further combiner 10, effect coherent combining of the signals from the combiner means 4 to form the composite signal at the output of the combiner 10. As already explained the delay

means 6 operates to mitigate the difference between these mean paths and in combination with scaling means 8 the combiner 10 operates to maximum ratio combine the received signals thereby forming at an output thereof the final composite signal representative of the wanted data signal.

In order to recover the data for a particular user, the data detector 12, operates to cancel the contemporaneously detected unwanted signals from the wanted signal as part of a detection process. For example, with time division CDMA the data detector operates to effect a joint detection process, known to those skilled in the art, which has an effect of cancelling the unwanted signals from the wanted signals.

A receiver which operates in accordance with that presented in Figure 1, must be provided with means for effecting calculation of the substantially complicated ESPRIT algorithm as well as the data processing means to effect cancellation of the interfering signals as effected by the data detector 12. Furthermore the requirement for time alignment effected by the delay means 6, in combination with the maximum ratio combining of each of the versions of the radio signals, provided by the adaptive antennas amounts to a considerable number of computations which are representative of an overhead in detection of the data for each user.

It is therefore an object of the present invention to provide a receiver for detecting and recovering data from wanted wide band radio signals in the presence of like or similarly modulated unwanted radio signals with a substantially reduced number of data processing calculations. It is a further object of the present invention to provide a substantially simplified receiver than is hitherto known.

The present invention resides generally in a receiver having a plurality of antennas, each of which is coupled to a temporal filter having a number of scaling coefficients which

are adapted in accordance with error-signals derived from the wanted radio signal. As a result the operations of beam steering and data detection in the presence of interfering signals are combined within a temporal and spatial filter matrix having coefficients which are optimised for the user being detected.

According to the present invention there is provided a radio communications receiver for use in recovering data from radio signals which reach the receiver via a plurality of different paths, each path being associated with one of a plurality of different mean delays, said receiver comprising a plurality of antennas arranged to detect said radio signals, each antenna providing a data signal representative of a version of the detected radio signals, a plurality of scaling filters, each of which is coupled to a corresponding one of the plurality of antennas, each scaling filter operating to scale the data signal with a plurality of scaling coefficients, a combiner means coupled to the plurality of scaling filters, which operates to combine the scaled data signals into a composite signal, and a data detector means which operates substantially to recover the data from the composite signal.

The receiver may have a data detector controller, coupled to the plurality of scaling filters which operates to adapt the scaling coefficients. The data detector may adapt the scaling coefficients consequent upon an error signal derived from the composite signal, to the effect of substantially improving the probability of correctly recovering the data.

By providing an adaptive antenna system having a plurality of antennas operatively coupled to a corresponding temporal scaling filter to which each version of the radio signals detected by each antenna is fed, the operations of adapting the antenna, combining, time aligning the signals with different mean delays and maximum ratio combining are

effected in a single adaptive antenna system. Furthermore by adapting the coefficients in accordance with an error signal derived from the wanted signal, interference caused by unwanted signals from other users transmitting these unwanted radio signals may be cancelled thus facilitating detection of the wanted radio signal.

Advantageously, the receiver may further include means for generating digital signal samples representative of the data signals. A plurality of the data signal samples may be representative of a datum of the data. The signals may have been generated in accordance with code division multiple access, in which case the plurality of samples representative of a datum may correspond to at least part of a spreading code. Each scaling filter may operate to scale each of the plurality of signal samples, with one of the plurality of scaling coefficients

Advantageously, the receiver may further include a decimating filter coupled to the combiner and arranged to form a sample representative of the datum from the composite signal. The composite signal may be decimated from a chip-rate to a symbol rate.

The code division multiple access signals may be time division-code division multiple access signals. The code division multiple access signals may be direct sequence code division multiple access signals.

According to another aspect of the present invention there is provided a method of recovering data from radio signals which reach a receiver via a plurality of paths associated with one of a plurality of different mean delays, the method comprising the steps of; using a plurality of antennas to detect each of a plurality of versions of the radio signals which include wanted radio signals representative of the data; generating for each of the versions a data signal

representative of the version of the radio signals; scaling each data signal with a plurality of scaling coefficients; combining the scaled plurality of data signals to form a composite signal; and recovering the data from the composite signal.

One embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings wherein;

FIGURE 2 is a schematic representation of a mobile radio telephone system;

FIGURE 3 is a schematic block diagram of a receiver which operates to detect and recover data from radio signals, communicated within the mobile radio telephone system shown in Figure 2; and

FIGURE 4 is a schematic block diagram of an antenna system forming part of the receiver shown in Figure 3.

An example embodiment of the present invention will be illustrated with reference to a mobile radio telecommunications system arranged to operate in accordance with time division-code division multiple access (TD-CDMA). Figure 2 provides an illustrative representation of such a mobile radio telephone system.

In Figure 2 three base stations BS, are shown to be interconnected via a mobile network infra-structure, Net. Data is communicated between mobile stations MS and the base stations BS, by transmitting and receiving radio signals 11, between the base stations BS and the mobile stations MS operating within a radio coverage area provided by each of the base stations. The radio coverage area is shown illustrated as a broken line 21, and serves to indicate a boundary within which radio communications can be effected

with the mobile stations MS. In the present illustrative embodiment the mobile stations MS communicate with the base stations BS using radio signals generated in accordance with TD-CDMA. A more detailed explanation of the way in which data is communicated using a time division CDMA system is provided in an article, entitled „Performance of a Cellular Hybrid C-TDMA Mobile Radio System Applying Joint Detection and Coherent Receiver Antenna Diversity" by G. Blanz, A. Klein, M. Naßhan and A. Steil published in the IEEE Journal on Selected Areas in Communications, Volume 12, no. 4, May 1994 at page 568, the content of which is incorporated herein by reference.

Communication of information in accordance with TD-CDMA can be characterised with respect to other multiple access systems in that data from a plurality of mobile stations is transmitted contemporaneously in one of a plurality of time slots into which a common radio frequency carrier signal is divided. In order to separate data transmitted from different mobiles, the data is convolved with a spreading code which identifies the mobile or user associated with the data. At a receiver, the radio signals are detected and down converted, and the data is recovered from the radio signals by comparing the received signal with the spreading code associated with the mobile station from which the radio signals were sent. Correspondingly, other radio signals received within the same time slot are regarded as interfering signals. It is a characteristic of time division-CDMA that in order to detect and recover data from the received radio signals other interfering signals must be estimated and cancelled from the wanted radio signal. This process is known as joint detection.

An example of a receiver which operates within the base station of the mobile radio system shown in Figure 2, is illustrated in Figure 3. In Figure 3 a plurality of antennas 14 are shown to be connected to an adaptive antenna system 16

forming part of a receiver 18. The antennas 14 form an antenna array 20, for detecting radio signals. Furthermore, as will be explained in more detail shortly, with reference to Figure 4, the antennas form a beam projecting from the antenna array, within which radio signals arriving from within the volume formed by the beam add coherently thereby increasing the power of the received signal with respect to noise power.

The adaptive antenna 16, forms a composite signal z_i, which is fed to an input of an adder 24, which in combination with a reference signal k_i, fed to a second input of the adder 24, forms an error signal e_i fed to a detector controller 26. The reference signal k_i is formed by a reference signal generator 28 from an estimate of the impulse response of the channel h_i and a sequence of hypothetical data symbols which may have contributed to the detected data symbol. The hypothesised data symbols are fed from a data store 30 to a shift register formed by register stages 29 in the reference signal generator 28. Also shown in Figure 3 is an initialisor 32, which operates to estimate an impulse response of a communications channel through which the radio signals have passed and which generates an initial set of antenna coefficients $a_{i,init}$ which are fed to the detector controller 26. Also connected to the output of the adder 24, is a data detector 34, which operates to recover data symbols from the error signal e_i formed by the adder 24. The adaptive antenna system 16 is shown in more detail in Figure 4 where parts also appearing in Figure 3 bear identical numerical designations.

In the illustration of the antenna system shown in Figure 4, only three antennas 14 are shown, which are connected to three finite impulse response filters 36, 38, 40, forming part of the adaptive antenna system 16, via a down converter and analogue to digital converter 48. Each of the finite impulse response filters 36, 38, 40, comprises a plurality of

stages 42, which serve to delay the version of the received radio signals by a chip period. The finite impulse response filters further include a plurality of scalers 44, which operate to scale the delayed versions of the received radio signals by a scaling coefficient designated $a_{n,m}$ where n is an index corresponding to the antenna and m is the coefficient corresponding to the m-th tap of the filter. Each of the scaled versions of the received radio signals are thereafter fed to a combiner 46, which operates to combine the outputs from all of the finite impulse response filters 36, 38, 40, to form the composite signal z_i fed at the chip-rate to an output 22, which is fed to the first input of the adder 24 of the receiver shown in Figure 3 to form the error signal e_i. In between the adaptive antenna system 16 and the adder 24 is a decimating filter 23 which operates to convert the chip-rate symbol into a symbol rate signal by decimating the signal accordingly.

Operation of the receiver will now be described with reference to the detection of TD-CDMA signals. However, as will be appreciated the receiver can be readily used with direct sequence CDMA. The receiver controller 26, operates with reference to the error signal e_i to adapt the channel impulse response estimate h_i and the antenna coefficients $a_{n,m}$ which are fed to the adaptive antenna system 16. The coefficient of each of the scalers in each of the finite impulse response filters is adapted to the effect of minimising the error signal e_i as will be explained shortly. The error signal e_i is formed by comparing the reference signal k_i generated by convolving hypothesised data symbols fed from the data store 30 to the reference signal generator 28 which convolves the hypothesised symbols with the impulse response estimate of the channel. The convolution sum is formed by multipliers 31 and a second adder 33, from the contents of the shift registers 29, following a well established technique. An initial estimate of the impulse response of the channel $h_{i,init}$ is generated by the initialisor

32 from a training sequence transmitted with the received TD-CDMA signals in accordance with a technique well known to those skilled in the art. Furthermore, as already explained the initial estimates of the antenna coefficients known as a temporal and spatial impulse response $a_{n,m,init}$ are generated and fed to the detector controller 26.

The filter bank shown in Figure 4 operates to perform the joint tasks of adaptive antenna interference cancellation, maximum ratio combining, and joint detection, which are performed separately by the receiver shown in Figure 1. The filter bank forms a wide band adaptive antenna but includes more taps in order to perform the tasks of maximum ratio combining and despreading. Thus, the adaptive antenna 16, has a considerably larger delay span and there is a larger number of taps. All tasks are performed jointly in the filter bank which performs temporal and spatial filtering depending on the filter coefficients $a_{n,m}$. Thus the suffix n represents a spatial filter component whereas suffix m represents a temporal filter component. In the following analysis by way of explanation all coefficients $a_{n,m}$ are collected into a single vector $\bar{a}$ with the assignment of indices to positions in the vector being substantially arbitrary. Adaptation of the filter coefficients $a_{n,m}$ is therefore given by equation 1, which corresponds to an adaptation of the antenna coefficients in accordance with a least mean squares adaptation algorithm further details of which are provided in our co-pending UK patent application, serial number 9 804 785.5 the contents of which are incorporated herein by reference.

Data communicated from, for example, a mobile station denoted $d_u(t)$ is arranged to generate a spread spectrum radio signal by convolving the data $d_u(t)$ with a spreading code. Individual symbols of the code, known as chips, include pulse shaping to provide appropriate limitation and spectral shaping of the frequency bandwidth occupied by the radio

signals. Using the symbol $\otimes$ for convolution, the radio signals communicated in accordance with a TD-CDMA system, after sampling the continuous valued received signal at the chip rate can be expressed as given in equation 1, where $d_u(t)$ is at the symbol rate.

$$r(t) = \sum_u c_u(t) \otimes h_u(t,\tau) \otimes d_u(t) + n(t) \qquad (1)$$

In equation (1), $r(t)$ is the continuous valued received signal with contributions from u transmitters sampled at the chip rate, $h_u(t,\tau)$ the channel impulse response sampled at the chip rate for transmitter u, $d_u(t)$ the data symbols from transmitter u, $c_u(t)$ the spreading code for transmitter u (including the chip modulation) at the chip rate and $n(t)$ is continuous valued additive white Gaussian noise sampled at the chip rate.

Using the symbol $\otimes$ for convolution radio signals received at each individual antenna of an antenna system having a plurality of antenna branches p can be described by equation (2):

$$r_p(t) = \sum_u c_u(t) \otimes h_{p,u}(t,\tau) \otimes d_u(t) + n(t) \qquad (2)$$

The channel impulse responses $h_{p,u}(t,\tau)$ now describes the channels between the transmitter and the individual antenna branches each of which has a different channel impulse response. In case of time variance the channels $h_{p,u}(t)$ also become time variant.

Adopting a matrix notation $\vec{r}$ is a vector of received signal samples, $\vec{n}$ is a vector of noise samples, wherein the element index of these vectors describes the sample time in symbols and the antenna branch.

The existence of several branches in an adaptive antenna system introduces spatial over-sampling. Therefore, in matrix form the shift from one column to the next column of the matrix is represented as not one sample, but a number of samples corresponding to the number of antenna elements. For each transmitter (*u1*, *u2*) the combined channel impulse response can be expressed as a matrix $H(u1)$, $H(u2)$, so that the contribution of each transmitter $\vec{r}1$ and $\vec{r}2$ is described by equation (3):

$$\vec{r}1 = H(u1)d(u1) \qquad \text{and} \qquad \vec{r}2 = H(u2)d(u2) \qquad (3)$$

For the signal samples received at the receiver, a total combined channel matrix $\vec{H}$ is formed by the sub-matrices $H(u1)$ and $H(u2)$, as given by equation (4):

$$\vec{r} = \left[H(u1)H(u2)\right]\begin{bmatrix} d(u1) \\ d(u2) \end{bmatrix} + \vec{n} = \vec{H}\vec{d} + \vec{n} \qquad (4)$$

The matrix notation used in equation (4), has been described for the case that the symbol sub-vectors contain all symbols for one transmitter and the received signal is arranged in sub-vectors of equal sampling time, in which each sub-vector the sub-index describes the branch number.

Obviously, any arrangement of vectors $\vec{r}$ and $\vec{d}$ is possible and the structure of the matrix $\vec{H}$ varies accordingly because the matrix row index must correspond with the index of the vector $\vec{r}$ and the matrix column index corresponds with the index of the vector $\vec{d}$. The time variance destroys the symmetry of the channel matrix $\vec{H}$ that holds in the time-invariant case. Hence in matrix notation of the received signal $\vec{r} = \vec{H}\vec{d} + \vec{n}$. the vector $\vec{d}$ is the data to be recovered. The vector $\vec{r}$ is composed of individual sub-vectors (one for every antenna element), with each sub-vector consisting of chip-rate samples.

All scaling coefficients for all branches are described by a vector $\vec{a}_u$, which consists of sub-vectors for each transmitter. The convolution with this coefficient sub-vector $\vec{a}_u$ and the received signal vector $\vec{r}$ results in a vector of composite signal samples $\vec{z}_u$ which no longer contains interference from other transmitters but may still contain inter-symbol interference. The inter-symbol interference is removed by a suitable means such as, for example, an equaliser as effected by the data estimator 42, in the data detector 14, shown in Figure 3. Introducing the convolution matrix $\vec{A}_u$ for the vector $\vec{a}_u$ and R for the vector $\vec{r}$ this convolution can be written in matrix form as expressed by equation (5):

$$\vec{z}_u = \vec{a}_u \vec{R} \qquad \text{or} \qquad \vec{z}_u = \vec{A}\vec{r}_u \tag{5}$$

The simplest method of adapting the antenna coefficients is the well-known LMS array, which operates to adapt the coefficients to the effect of minimising a difference between a combined signal produced by the adaptive antenna, and a reference signal according to the LMS algorithm. If the transmitted symbols are used as the reference signal the adaptive antenna performs separation and partial equalisation contemporaneously as with TD-CDMA reception. The adaptation criterion demands that $\vec{z}_u$ match $\vec{d}_u$ as closely as possible. As such, equation (6) delivers a steady-state solution of the LMS algorithm, '+' denoting the matrix pseudo inverse.

$$\vec{a}_u = \vec{R}^+ \vec{d}_u \tag{6}$$

Now the coefficients for the individual adaptive antennas, which can be regarded as spatial decimating filters, are known and the data from any transmitter u can be estimated, in accordance with equation (7):

$$\hat{\hat{d}}_u = \vec{A}_u \vec{r}_u = \vec{R}\vec{a} \qquad (7)$$

The adaptation of the antenna coefficients $a_{n,m}$ are effected in this example embodiment using the equation (8), (9) and (10), which describes a special case of a least mean squares adaptation algorithm:

$$\vec{a} = \vec{L}_a \bullet \vec{a} - \vec{\mu}_a \bullet e\vec{d}' \qquad (8)$$

$$\vec{H} = \vec{L}_a \bullet \vec{a} - \vec{\mu}_a \bullet e\vec{d}' \qquad (9)$$

$$R = L_R R + \mu_R e\vec{d}' \vec{H} \qquad (10)$$

The leakage factors for each of the above equations are provided in equations (11), (12) and (13):

$$\vec{L}_a = 1 - \alpha\vec{\mu}_a \qquad (11)$$

$$\vec{L}_W = \begin{cases} 1 - \beta\vec{\mu}_W & if |\vec{W}|^2 \geq 1 \\ 1 + \beta\vec{\mu}_W & if |\vec{W}|^2 < 1 \end{cases} \qquad (12)$$

$$\vec{L}_R = \begin{cases} 1 - \rho\vec{\mu}_R & if |\vec{R}|^2 \geq 1 \\ 1 + \rho\vec{\mu}_R & if |\vec{R}|^2 < 1 \end{cases} \qquad (13)$$

For the example of time division-coded division multiple access (TD-CDMA), the antenna beam formed by the adaptive antenna system must be steered differently according to the angle of arrival of the versions of the radio signals from the transmitter for that user. As a result, for each of N users to be detected, N different received signals result after combining. In the known receiver shown in Figure 1, N channel coefficients must be estimated for a received signal in order to detect N users. However in the joint detector effected by the data processor 12, each user requires a

different received signal to be generated and for each received signal N channel coefficients must be estimated, thereby squaring effectively the number of total channel estimations from N to N squared. The joint detection algorithm effected by data processor 12 acting on each received signal, detects one user only and all other users are treated as interferrers. Yet, for proper multi-user separation with conventional joint detection algorithms, all impulse responses must be estimated and used in the joint detection process to provide the detection and recovery of data from one user. Thus with the receiver as shown in Figure 1, the antenna and combiner coefficients must be differently optimised for each user, whereas the receiver according to the present invention may operate to optimise contemporaneously the scaling coefficients to the effect of detecting data from all users as a single operation.

As will be appreciated by those skilled in the art various modifications may be made to the example embodiment without parting from the scope of the present invention. For example, the receiver herein before described could be used to recover data from any spread spectrum signal.

CLAIMS:

1. A radio communications receiver (18) for use in recovering data from radio signals which reach the receiver via a plurality of different paths, each path being associated with one of a plurality of different mean delays, said receiver comprising

- a plurality of antennas (14) arranged to detect said radio signals, each antenna (14) providing a data signal representative of a version of the detected radio signals,
- a plurality of scaling filters (36, 38, 40), each of which is coupled to a corresponding one of said plurality of antennas (14), each scaling filter (36, 38, 40) operating to scale the data signal with a plurality of scaling coefficients ($a_{n,m}$),
- a combiner means (46) coupled to said plurality of scaling filters (36, 38, 40), which operates to combine the scaled data signals into a composite signal (z_i), and
- a data detector means (34) which operates substantially to recover said data from said composite signal.

2. A radio communications receiver as claimed in Claim 1, and further comprising

- a detector controller (26) coupled to said plurality of scaling filters (36, 38, 40) which operates to adapt said scaling coefficients ($a_{n,m}$) to the effect of substantially improving a probability of correctly recovering said data.

3. A radio communications receiver as claimed in Claim 2, wherein the detector controller (26) operates to adapt said scaling coefficients ($a_{n,m}$) consequent upon an error signal (e_i) derived from said composite signal (z_i).

4. A radio communications receiver as claimed in Claim 1, 2 or 3, and further comprising

- means (48) for generating for each of said data signals digital signal samples representative of said data signals, a

plurality of said signal samples being representative of a datum of said data.

5. A radio communications receiver as claimed in Claim 4, wherein said radio signals are generated in accordance with code division multiple access, wherein each said datum is represented as a plurality of data symbols, which data symbols form at least part of, or corresponds to, a spreading code indicative of a transmitter from which the radio signals were generated.

6. A radio communications receiver as claimed in any of Claims 1 to 5, wherein each of said scaling filters (36, 38, 40) comprises,

- a shift register to which said data signal samples are fed, and
- an associated plurality of multipliers (44) coupled to said shifter register and arranged to scale said data signal samples with said plurality of scaling coefficients.

7. A radio communications receiver as claimed in any of Claims 2 to 6, wherein said data detector (34) further includes

- means (28) for generating a reference signal (k_i), and means (24) for forming said error signal (e_i) by comparing said reference signal with said composite signal.

8. A radio communications receiver as claimed in Claim 7, wherein said means (28) for generating said reference signal comprises

- a reference signal former (28) being fed from a data store (30) with a plurality of possible symbols which could have effected the datum being detected by said data detector and a channel impulse response estimate ($\bar{h}$), said reference signal former (28) operating to generate said reference signal

sample by convolving said plurality of possible symbols with said channel impulse response estimate ($\tilde{h}$).

9. A radio communications receiver as claimed in Claim 8, wherein said channel impulse response estimate is adapted by said data detector controller (26) in accordance with said error signal.

10. A radio communications receiver as claimed in Claim 9, wherein said data detector further includes
- a data estimator (34) coupled to said means (24) for forming said error signal (e_i), which operates to recover said data from said error signal.

11. A radio communications receiver as claimed in any preceding claim, and further comprising,
- a decimating filter (23) coupled to said combiner (46) and arranged to form a sample representative of said datum, from said composite signal.

12. A radio communications receiver as claimed in any preceding Claim, wherein said radio signals are code division multiple access radio signals.

13. A radio communications receiver as claimed in any preceding Claim, wherein said code division multiple access radio signals are time division-code division multiple access radio signals generated by convolving said data to be communicated with a pre-determined spreading sequence.

14. A radio communications receiver as claimed in any of Claims 1 to 12, wherein said code division multiple access radio signals are direct sequence code division multiple access radio signals generated by multiplying said data to be communicated with a pre-determined spreading sequence.

15. A mobile radio communications apparatus, comprising at least one base station, and at least one mobile station, wherein at least one of said base stations or said mobile stations includes a receiver as claimed in any of the preceding claim.

16. A method of recovering data from radio signals which reach a receiver via a plurality of paths associated with one of a plurality of different mean delays, said method comprising the steps of;

- using a plurality of antennas to detect a plurality of versions of said radio signals which include wanted radio signals representative of the data;
- generating for each of said versions a data signal representative of the version of said radio signals;
- scaling each data signal with a plurality of scaling coefficients;
- combining said scaled plurality of data signals to form a composite signal; and
- recovering said data from said composite signal.

17. A method as claimed in Claim 16, and further including the step of

- adapting said plurality of scaling coefficients so that a probability of correctly recovering said data is substantially improved.

18. A method of recovering data from radio signals as claimed in Claim 17, and further including the step of,

- forming an error signal (e_i) from said composite signal sample (z_i) and adapting said scaling coefficients ($a_{n,m}$) so that said error signal is minimised.

19. A method of recovering data from radio signals as claimed in Claim 18, and further including the step of,

- forming reference signals from a plurality of reference symbols representative of a possible combination of symbols which have an influence on said composite signal;
- generating said error signal by comparing said reference signals from said composite signal.

20. A method of recovering data from radio signals as claimed in Claims 19, wherein the step of generating said reference signals further includes the steps of;
- generating an estimate of the impulse response ($\bar{h}$) of the communications channel through which the received radio signals have passed;
- convolving said channel impulse response with said reference symbols to form said reference signals.

21. A method of recovering data from radio signals as claimed in any of Claims 16 to 20, wherein said radio signals are code division multiple access radio signals.

22. A method of recovering data as claimed in any of Claims 16 to 21, wherein the code division multiple access radio signals are time division code division multiple access radio signals.

23. A method of recovering data as claimed in any of Claims 16 to 21, wherein the code division multiple access radio signals are direct sequence code division multiple access radio signals.

24. A radio communications receiver as herein before described with reference to Figures 2, 3 and 4 of the accompanying drawings.

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Application No: GB 9903054.6
Claims searched: 1-24

Examiner: Keith Williams
Date of search: 26 August 1999

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): H4L (LDDRCP, LDDRCW, LDDRCX, LDDRQ, LDDRS, LDDRX)

Int Cl (Ed.6): H04B 1/707, 7/08, 7/216; H01Q 3/26

Other: Online EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0667686 A2	NEC Corp. - see abstract (& US 5598428)	1,16
A	EP 0650268 A1	AT&T Corp. - see abstract	1,16
A	US 4752969	Rilling - see abstract	1,16

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